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- to serve as a key global resource for the acquisition, assessment, and dissemination of industry information, providing critically important information to decision-makers at all levels of the industry; and
- to aggressively seek out technological opportunities and facilitate the transfer and implementation of those technologies in collaboration with industry partners.

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THE EFFECTS OF WHITE WATER CLOSURE ON THE PHYSICAL PROPERTIES OF LINERBOARD

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ABSTRACT

Many mills continue to look for ways to reduce fresh water input into the paper machine. As fresh water to the paper machine decreases, detrimental substances in the white water build up. Furthermore, increasing the use of recycled fibers will also significantly increase the content of detrimental substances in white water. The detrimental substances include both cationic and anionic species. In order to accurately quantify the effects of these substances, the physical properties of handsheets made from a Formette Dynamique were studied. A partial factorial design of experiments investigated the effects of calcium, sodium, lignin, xylan, pH, and fines on the physical properties of paper, including burst, ring crush and z-directional tensile. The level of contaminants varied from that found an average open mill to that of an average closed mill. It was found that the high levels of calcium and sodium negatively impacted the physical properties, while the anionic organic substances actually improved the physical properties. The increased level of fines had the largest impact, improving the strength of the board.

INTRODUCTION

The pulp and paper industry continues to look into mill closure, in particular white water closure around the paper machine. Contaminants will increase when white water streams are closed. These contaminants have been discussed in the literature [1-7]. The contaminants include organic, inorganic, cationic and anionic substances. Typical contaminant levels of common species for liner board mills are listed in Table I. The effects of these contaminants on the physical properties of paper, specifically linerboard, have not been adequately discussed. Dexter [2] presented a table that qualitatively presented the effects of contaminants on the physical properties of linerboard. The table suggested both positive and negative benefits of closure on the physical properties. However, this table gave only a qualitative description of the results. Even though many mills have operated under zero discharge for over 25 years, "…there appears to be a need for quantitative information defining the impact on product quality which may result due to closure of the water system" [1].

Traditional linerboard mills have had relatively simple wet end chemistry situations. However, these mills now try and run with as much recycle as possible in the furnish. One of the consequences of recycled furnish is a loss in strength which a mill may counter by adding starch for dry strength improvement. Furthermore, some linerboard mills add clay or other fillers to the top sheet to improve opacity, basically producing a prettier sheet. Thus wet end chemistry and paper properties for current linerboard mills are quite different from the traditional acid and alum system.

While there have been some publications that determine the impact of closure on papermaking in the literature [8-11]. The qualitative consequences and results of white water closure are generally well understood, but there is little information regarding specific quantitative examples. Of course, like most of the research in the paper area, many of the systems are machine specific, and therefore results can vary from machine to machine, region to region. This means that more genetic studies are needed. In this work, the effects of water closure on the linerboard properties at different water closure degrees were studied using a Formette Dynamique. Although the handsheets made from a Formette Dynamique are different from the papers made from a real paper machine, it is believed that from a general point of view, the results from a laboratory Formette Dynamique are still valid for predicting the effects of water closure on the paper physical properties.

EXPERIMENTAL

Materials, Equipment, and Procedures

A Georgia linerboard mill supplied furnish for these experiments. The furnish came right after the refiners at approximately 4% consistency. The top furnish was 100% virgin, while the bottom furnish was 65% virgin and 35% OCC (old corrugating container). To simulate the white water closure, different amounts of inorganic salts and organic components were added in the diluted furnishes. The organic components added to the furnish were model lignin (Indulin C, Westvaco) and Xylan (Fisher). Calcium chloride and sodium chloride (Fisher) were used to adjust the cationic levels in the furnish. The pH was adjusted with sulfuric acid and sodium hydroxide. Alum (Fisher) was added to the furnish as required. Tap water was used to dilute the furnish.

The fines contents in the furnishes were adjusted with a concentrated solution of fines. The fines were generated by rinsing furnish in a DDJ with a 200 mesh screen. The fines solution was concentrated by allowing the original filtrate to settle overnight. The top layer of water was removed, thus concentrating the remaining fines.

The furnish, stored in a cold room, was allowed to come to room temperature before use. Each experiment began by weighing out the necessary amount of furnish. The furnish whs then diluted with tap water to approximately 0.5%. The Indulin C, xylan, calcium, sodium, fines, and alum were added which made the consistency 0.5%. An anionic polymer was added (0.5 lb/ton) in accordance with the mill from which the samples originated. This polymer was thought to be a drainage and retention aid. The pH was adjusted to the desired value. This was done for both the top and bottom furnishes.

A Formette Dynamique was used to make directional handsheets. It was also possible to make a two-ply sheet with the Formette. The bottom sheet comprised 80% of the target basis weight of the two-ply sheet of 205 g/m^2. The bottom furnish was poured into the Formette and then the bottom sheet was made. When the sheet was almost finished, the top furnish was added and the top sheet formed. The Formette ran at 1500 m/min, with the pump pressure at 1.5 bar. The Dynamique made a 205 g/m^2 two-ply linerboard sheet. The bottom sheet constituted 80% by weight. The bottom sheet ranged from 30-40% recycle, while the top sheet was 100% virgin. Once finished, the sheets were removed and dried in a Johnson drum dryer at 15 psi of steam pressure. The sheets were then removed and conditioned before testing according to TAPPI standards. The physical properties, including burst, ring crush and z-directional tensile strength were measured according to TAPPI standard methods.

Experimental Design

In order to determine the importance of water closure on the physical properties this work utilized a partial factorial design of experiments. Six variables of interest can be seen, along with their values, in Table II.

This work grouped the two most prevalent cationic species together, i.e., the levels of sodium and calcium were changed at the same time. The same procedure was followed for the anionic organic compounds.

The partial factorial design of experiments was resolution V, which allowed interpretation of two-way interactions. The design called for 16 experiments, and four additional center points were run to determine the error and to test for curvature. Table III details the experimental runs.

RESULTS AND DISCUSSION

Burst

Table IV lists the p-values for each of the main effects and two-way interactions for burst. The p-value is a statistical evaluation of the likelihood that the result is not statistically significant. If a confidence level of 95% is selected, a p-value of 0.05 or less is considered statistically significant. Whenever there are two-way interactions present, it is necessary to discuss the interactions first. A two-way interaction implies that the factors in question behave differently together than they do when they are separate. This is basically an indication of positive and or negative synergy. It can be seen that the organic anionic substances, fines and pH were the only significant effects at 95% confidence. The metal ions and alum were significant at roughly 94% confidence. The organic anionic substances*pH and alum*pH interactions were the only interactions significant at the 95% confidence level.

Figure 1 shows the two-way interaction between alum and pH. At pH 6, the alum dosage has no effect on the burst. However, at pH 5, increasing the alum decreases the burst. The negative effect of increasing alum concentration at acid pH was also observed by Allen[12]. The reason for this difference is definitely related to the charge and structure characteristic of aluminum ions at different pHs. However, more work is needed for further understanding the real mechanism of alum effects on the burst at different pHs.

Figure 2 indicates that the effects of the anionic organic substances are dependent upon the pH as well. At a pH of 5, increasing the anionic organic substances greatly increases the burst from 105 to 125 psi. When the pH is 6, however, adding more organic substances to the system negligibly affects the burst. Figure 3 summarizes the main effects of contaminants on the burst. It can be seen that the organic anionic substances, fines, and pH increased burst while alum and other metal ions (sodium and calcium) had a slight negative impact.

Worth of mention here is the positive effect of organic substances on burst, which is in contrast with the results from other researchers[6, 13, 14]. The opposite results may in part result from the difference in pulp used and the organic substance level added. Springer[13] mentioned that two mechanisms are involved in the strength effects of organic contaminants. One results in a strength loss and the other a strength increase. At very low contaminants levels (less than several ppm), the strength loss mechanism dominates. As the contaminants level increases, the strength increase mechanism counteracts the strength loss mechanism. Because the anionic levels used in this research are relatively high, it is very likely that the second mechanism dominates. How the second mechanism improves paper strength is still not clear. A tentative explanation is that the organic contaminants improve the bonding strength between fibers just like dry strength additives, such as starch and polyacrylamide. This is more likely for xylan considering it similar chemical structure with starch. The pH dependence of anionic contaminants effect on burst may be related to the dissociation of association of hydrogen in these materials.

Figure 4 shows the effect of a simulated degree of closure on the burst. The higher the number in x-axis, the higher the degree of closure, and the '0' condition represents a sheet formed with just tap water and the anionic polymer. The trend in the graph is clear: increasing contaminants raises the burst strength by more than 25%.

Ring Crush

Table V reveals that the alum*pH was the only interaction significant at 95% confidence level, and by itself, the pH did not affect the ring crush. Figure 5 shows the main effects of different contaminants on the ring crush. Similar to the effects of contaminants on the burst, the ring crush is negatively affected by adding alum and other metal ions, but it is positively affected by adding anionic trashes. The fines had the greatest impact that is almost double the impact of the organic anionic substances. A certain level of fines can fill the cavities between fiber network and improve paper strength by increasing bonding areas. Increasing the alum decreased the ring crush. Changing the pH from 5 to 6 had no impact on the ring crush by itself, however, it does interact with alum as shown in Figure 6. Increasing the level of closure from a system defined as open (the low level) to a system modeled as closed (the high level) improves ring crush (Fig. 7). As the simulated degree of closure increased over 5 levels, ring crush increased from the mid 80's to around 115. This is more than a 35% increase.

Z-Tensile Strength

Table VI shows the p-values for the main effects and two-way interactions for z-tensile strength. pH was not significant as a main effect or as a two-way interaction. There were three two-way interactions that were significant (Figs. 8-10). Increasing the metal ions only decreased the z-tensile when the anionic level was low (Fig. 8). It is probable that at low levels, the anionic materials are more saturated with calcium and sodium, thus weakening their beneficial effect. In terms of white water closure this is not a problem because when the organic anionic substances are at a high level, the metal ions are also at a high level.

Increasing the organic anionic substances at a low fines level decreases the z-tensile strength, whereas at a high fines content there is no effect (Fig. 9). From a process point of view this may not be too critical because the levels of organic anionic substances and fines will increase together during the water closure. With a low alum dosage, the increase in fines has a more positive effect. For example, a 33% increase in z-tensile strength at 13 lb/ton of alum compared to a 10% increase at 18 lb/ton of alum was observed (Fig. 10).

Figure 11 shows the main effects on z-tensile strength. Again, metal ions decreased strength, while the organic anionic substances and fines increased the strength. Looking at a systemic increase in closure, one observes that the z-tensile strength improves (Fig. 12). The trend is very clear with a 25% improvement.

CONCLUSIONS

These results have shown that the increase in the metal ions, organic substances, and wood fines in white water closure may not have a detrimental impact upon the physical properties commonly measured for linerboard. Indeed, the data suggest that the physical properties will be improved if a closure white water is used. The burst was found to increase by 25-35%. Ring crush increased by 35-45%. The z-tensile strength increased by 25-45%.

The experiments revealed two-way interactions. From a closure perspective the more alkaline the papermaking conditions, the less improvement will be seen from the organic anionic substances for burst and ring crush. The improvement of paperboard strength by organic substances is more significant at low pH. High fines content interacts with the organic anionic substances to maintain z-tensile strength.

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Figure Captions

Figure 1. Effect of two-way interactions (pH*alum) on burst

Figure 2. Effect of two-way interaction (pH*organic anionic substances) on burst

Figure 3. Effect of simulated closure on burst

Figure 4. Main effects of burst

Figure 5. Effect of two-way interaction (pH*alum) on ring crush

Figure 6. Main effects of ring crush

Figure 7. Effect of simulated closure on ring crush

Figure 8. Effect of two-way interactions (organic anionic substances*metal ions) on Z-tensile

Figure 9. Effect of two-way interactions (fines*organic anionic substances) on Z-tensile

Figure 10. Effect of two-way interactions (alum*fines) on Z-tensile

Figure 11. Main effects of Z-tensile

Figure 12. Effects of simulated closure on Z-tensile

Table I: Typical Contaminant Levels in Linerboard Mills

	Average	Average	Average
	Open Virgin	Open Recycled	Zero discharge Recycled
Lignin, ppm	214	77	914
Carbohydrates, ppm	N/A	N/A	2930
Sodium, ppm	533	381	5000
Calcium, ppm	144	335	141
Aluminum, ppm	3.4	2.0	10
Magnesium, ppm	43	56	64
Maganese, ppm	1.6	1	0.4
Fines, %	20.1	14.5	30

Table II: Experimental Variables

Factors	-1	0	+1
Cationic			
Ca	100	250	400
Na	500	2250	5000
Anionic			
Lignin	25 ppm	100 ppm	175 ppm
Xylan	50 ppm	325 ppm	600 ppm
pH	5.0	5.5	6.0
Alum	13	15	18
Fines	8%	10%	12%

Table III: Experimental Design

Run order	Metal ions	Organic anionic substances	Fines	Alum	pH
1	1	-1	1	1	-1
2	0	0	0	0	0
3	1	-1	-1	1	1
4	0	0	0	0	0
5	1	-1	1	-1	1
6	-1	1	1	-1	1
7	-1	1	1	1	-1
8	0	0	0	0	0
9	1	1	1	1	1
10	-1	-1	-1	1	-1
11	-1	-1	1	-1	-1
12	1	1	-1	-1	1
13	1	1	-1	1	-1
14	-1	-1	-1	-1	1
15	-1	-1	1	1	1
16	1	1	1	-1	-1
17	1	-1	-1	-1	-1
18	-1	1	-1	1	1
19	0	0	0	0	0
20	-1	1	-1	-1	-1

Table IV: p-values for Burst

Factors	p-value
Metal ions	0.051
Organic anionic substances	<0.001
Fines	<0.001
Alum	0.056
pH	0.048
Organic anionic substances*pH	0.002
Alum*pH	0.014

Table V: p-values for Ring Crush

Factors	p-value
Metal ions	0.002
Organic anionic substances	<0.001
Fines	<0.001
Alum	0.003
pH	0.638
Alum*pH	0.030

Table VI: p-values for Z-tensile

Factors	**p-value**
Metal ions	0.004
Organic anionic substances	0.028
Fines	<0.001
Alum	0.002
pH	0.482
Metal ions*Organic anionic substances	0.003
Organic anionic substances*Fines	0.044
Fines*Alum	0.008

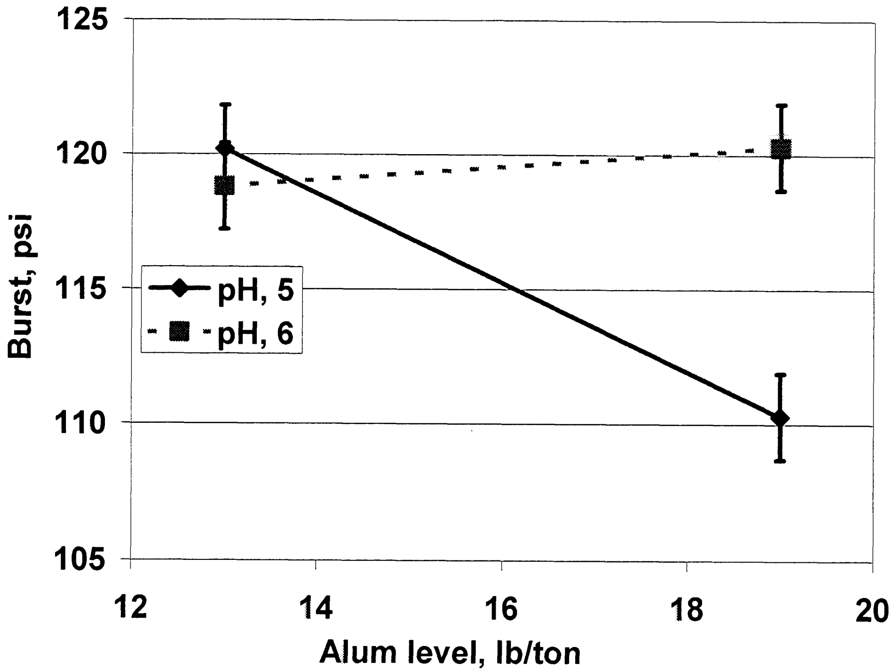

Figure 1. Effect of two-way interactions (pH*alum) on burst

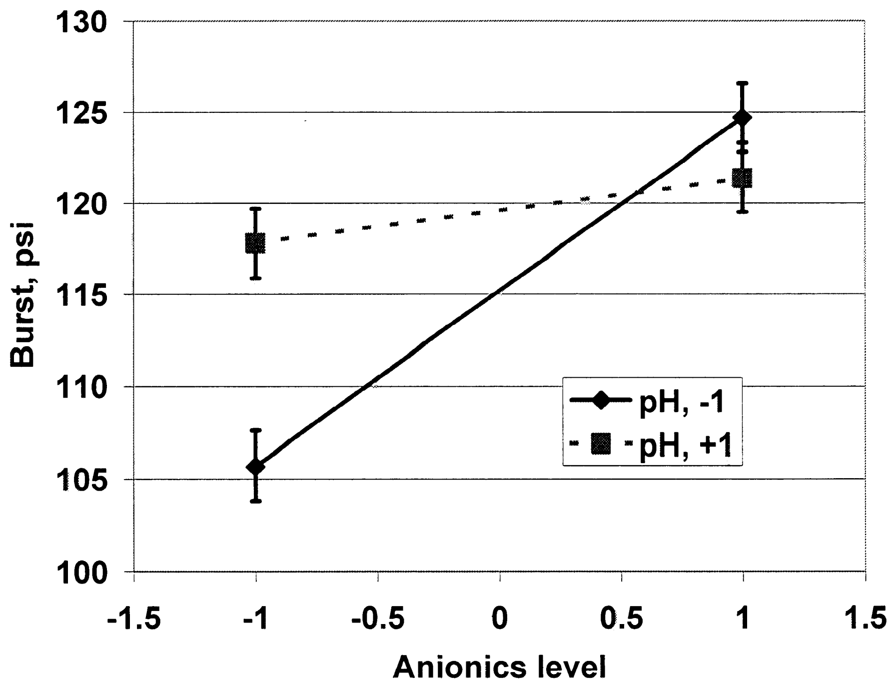

Figure 2. Effect of two-way interaction (pH*organic anionic substances) on burst

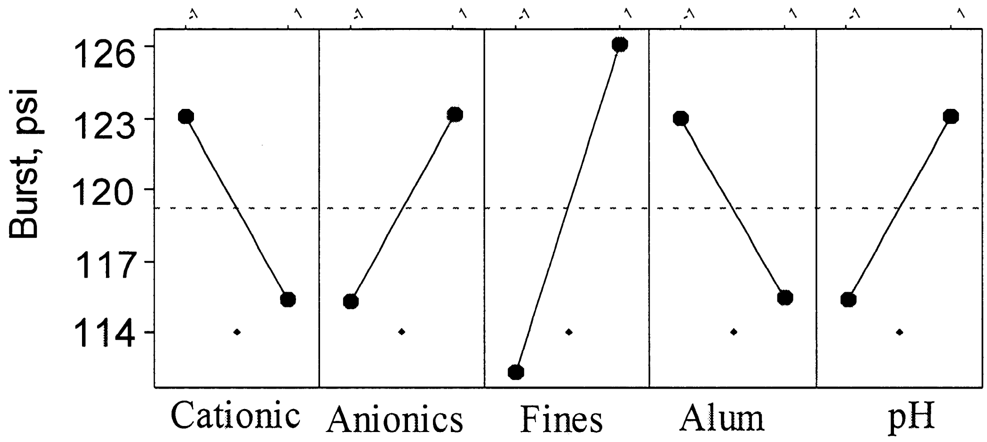

Figure 3. Main effects of burst

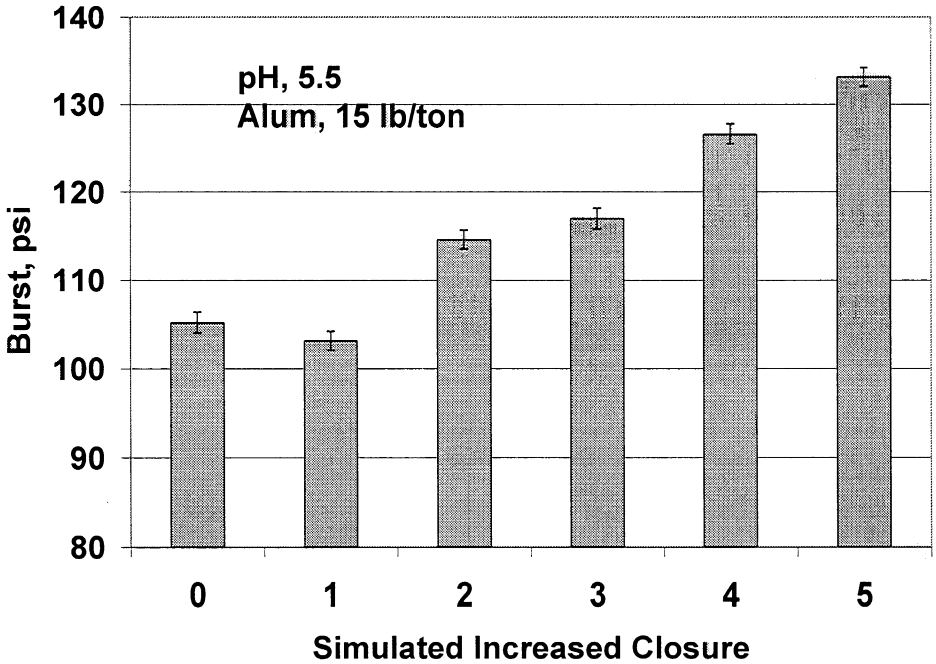

Figure 4. Effect of simulated closure on burst

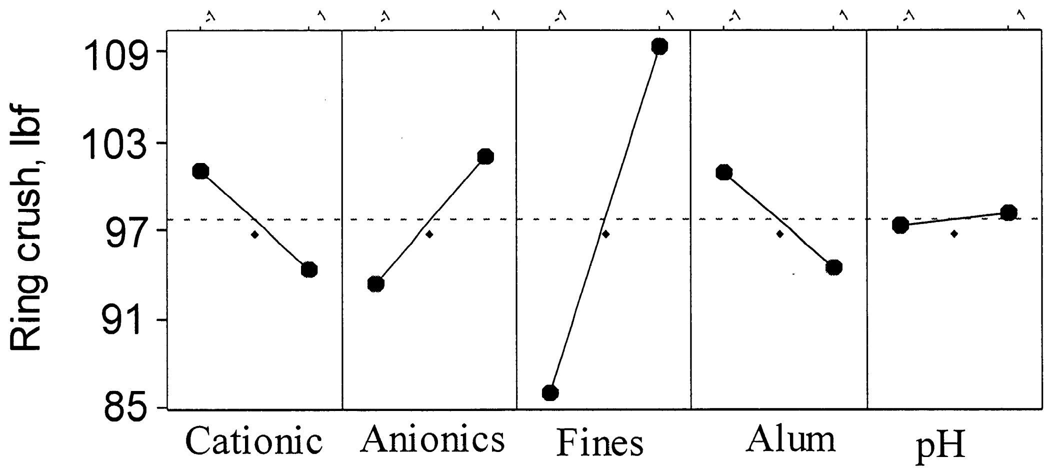

Figure 5. Effect of two-way interaction (pH*alum) on ring crush

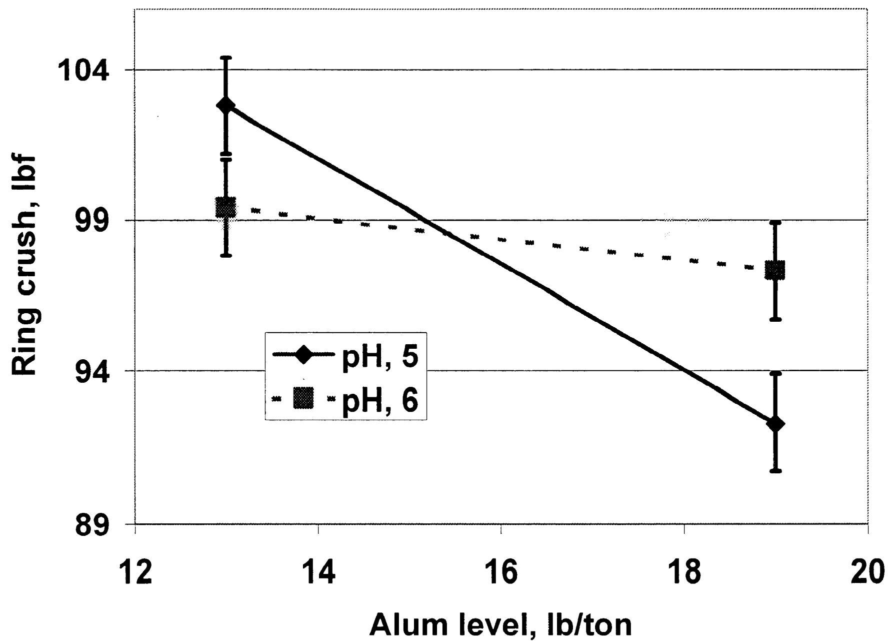

Figure 6. Main effects of ring crush

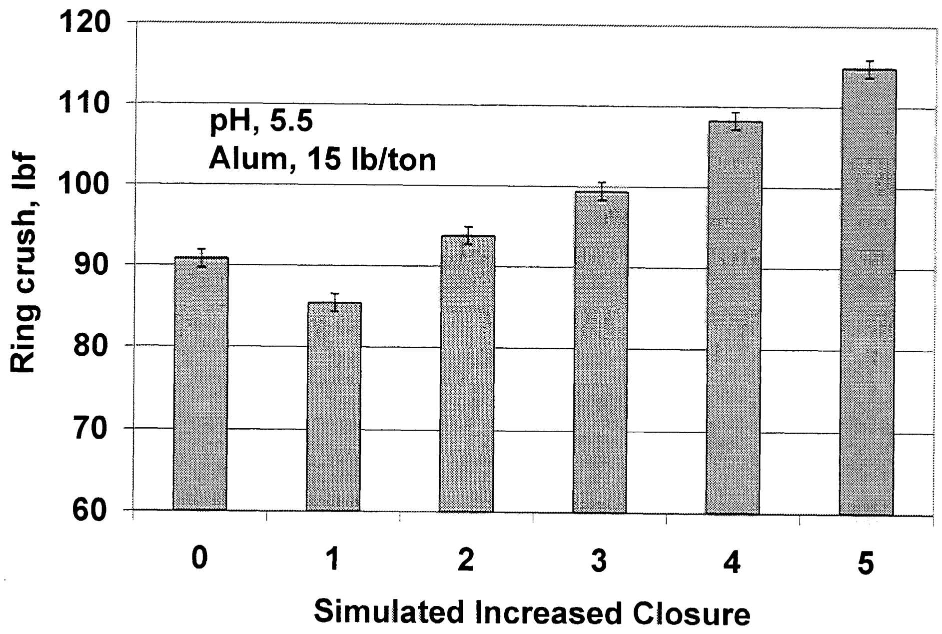

Figure 7. Effect of simulated closure on ring crush

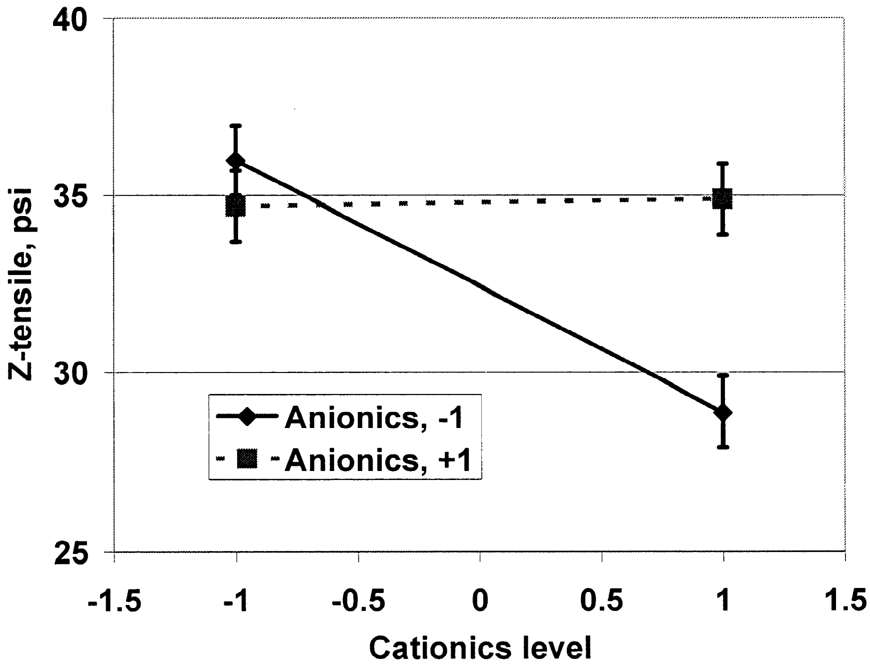

Figure 8. Effect of two-way interactions (organic anionic substances*metal ions) on Z-tensile

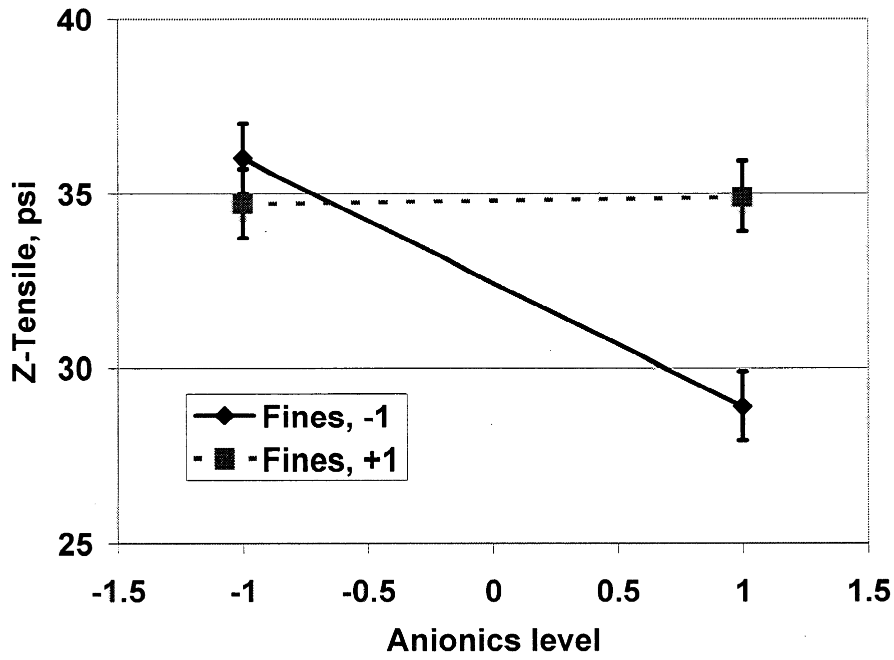

Figure 9. Effect of two-way interactions (fines*organic anionic substances) on Z-tensile

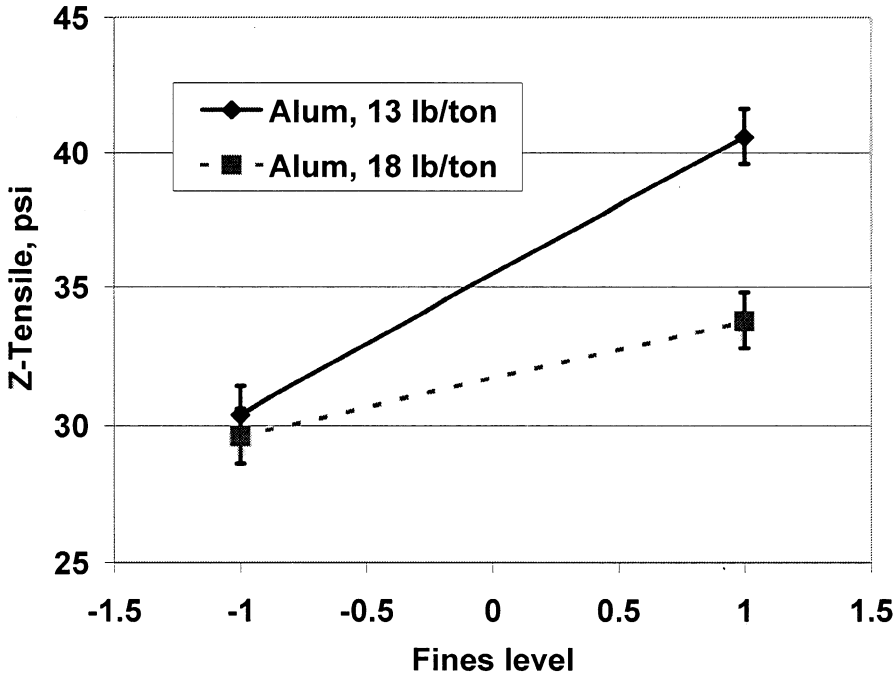

Figure 10. Effect of two-way interactions (alum*fines) on Z-tensile

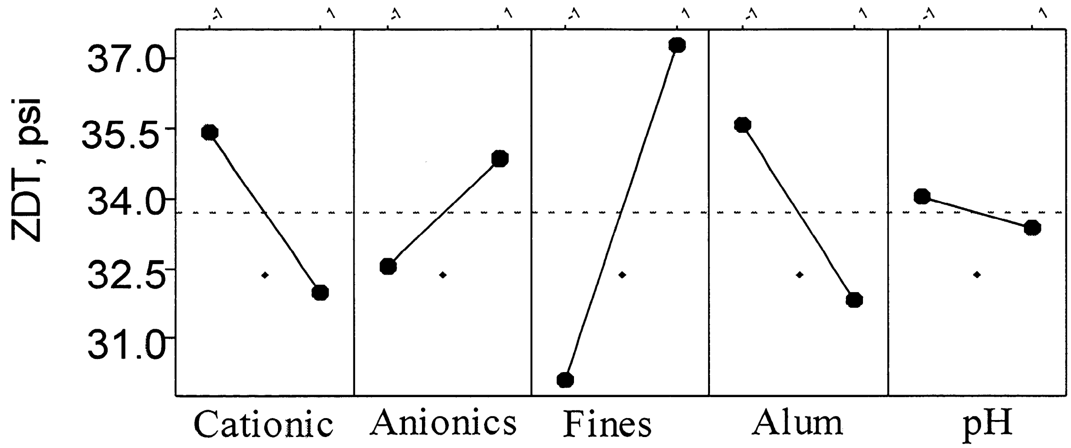

Figure 11. Main effects of Z-tensile

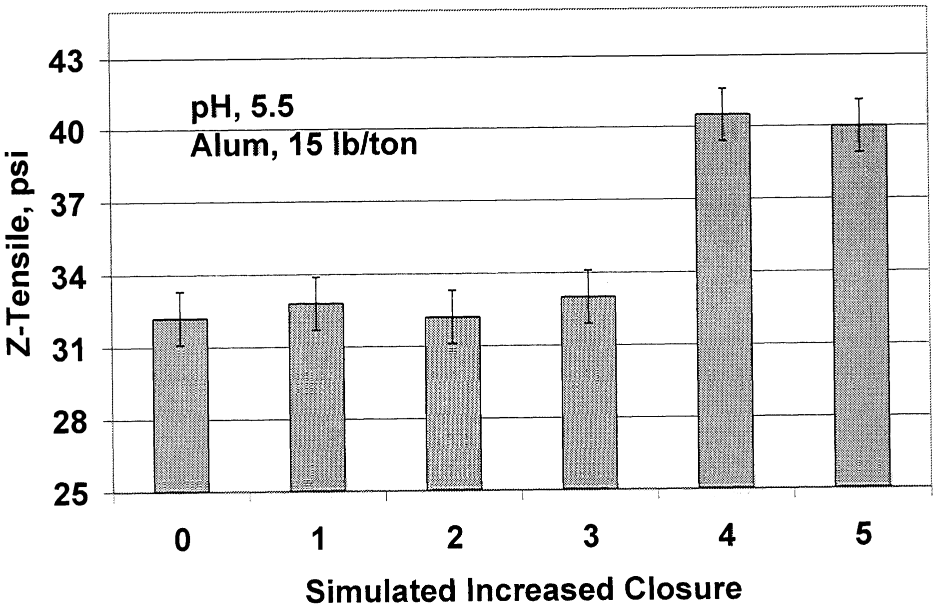

Figure 12. Effects of simulated closure on Z-tensile